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abstract

We report on the searches performed in the L3 experiment for pair–produced supersymmetric particles decaying with a single non–zero trilinear R–parity violating coupling, in $e^+ e^-$ collisions ranging from $\sqrt{s} = 189$ GeV up to 202 GeV.
No significant excess is seen on the studied final states so limits on production cross–sections of the considered processes are set. These limits are then interpreted into limits on supersymmetric particle masses within the framework of the constrained MSSM.

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SEARCH FOR R–PARITY VIOLATING DECAYS OF SUPERSYMMETRIC PARTICLES IN THE L3 EXPERIMENT.

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We report on the searches performed in the L3 experiment for pair–produced supersymmetric particles decaying with a single non–zero trilinear R–parity violating coupling, in $e^+ e^-$collisions ranging from $\sqrt{s}$ = 189 GeV up to 202 GeV.
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1 Supersymmetry and R–Parity.

The Minimal Supersymmetric Standard Model is an extension of Standard Model built on a symmetry between fermions and bosons, requiring a new set of particles to form the partners of the usual "standard" particles.

These supersymmetric partners have the same quantum numbers as their standard counterpart but have a different spin value[1].

This extension of particle spectrum in the matter sector leads to the apparition of lepton or baryon number violating trilinear terms in the superpotential[2,3]:

$$W = \lambda_{ijk} L_i L_j \bar{E}_k \ + \ \lambda'_{ijk} L_i Q_j \bar{D}_k \ + \ \lambda''_{ijk} \ \bar{U}_i \bar{D}_j \bar{D}_k \tag{1}$$

Here, L and Q are lepton and quark superfields isodoublets, whereas $\bar{E}$ and $\bar{U}, \bar{D}$ are lepton, up–like and down–like superfields isosinglets. Indices i, j, k correspond to the fermion generation. The baryon number is violated only in the last term.

As some combinations of these three terms lead to fast proton decay, it is common to get rid of the whole set by imposing the conservation of the discrete multiplicative quantity called R–parity[4]:

$$R_p = (-1)^{3B+L+2S} \tag{2}$$

where B, L and S are respectively the baryon, lepton and spin quantum numbers.

Another solution is to consider only one non–zero coupling amongst the three, invoking either lepton or baryon number conservation and thus violating R–parity.

When R–parity is not conserved, the Lightest Supersymmetric Particle (LSP) is no longer stable and will decay into Standard Model fermions. Supersymmetric particles can also be singly produced in $e^+ e^-$collisions, but this is not the topic of this article.

2 Phenomenology and analysis in $e^+ e^-$collisions.

Under the assumption that there was only one non–zero R–Parity violating coupling at a time, we have looked for the production of the following processes:

- $e^+ e^- \to \tilde{\chi}^0_1 \tilde{\chi}^0_1$,$\tilde{\chi}^0_i \tilde{\chi}^0_j$
- $e^+ e^- \to \tilde{\chi}^+_1 \tilde{\chi}^-_1$
- $e^+ e^- \to \tilde{\ell}^+_R \tilde{\ell}^-_R$, $\ell = e, \mu, \tau$

followed by the relevant R–Parity violating decays of these supersymmetric particles.

Different final states and search strategies are considered according to the relevant R–Parity violating coupling, developped in detail in the reference[5] and summarized in the following.

2.1 λ couplings

The following decays were considered:

$$\begin{array}{rcl} \tilde{\chi}^0_1 \tilde{\chi}^0_1 & \to & \ell^+\ell^-\nu \;\; \ell^+\ell^-\nu \\ \tilde{\chi}^0_j \tilde{\chi}^0_1 & \to & Z^*\tilde{\chi}^0_1 \tilde{\chi}^0_1 \to f\bar{f} \; \ell^+\ell^-\nu \;\; \ell^+\ell^-\nu \\ \tilde{\chi}^+_1 \tilde{\chi}^-_1 & \to & W^*\tilde{\chi}^0_1 \, W^*\tilde{\chi}^0_1 \to f\bar{f}' \; \ell^+\ell^-\nu \;\; f\bar{f}' \; \ell^+\ell^-\nu \\ \tilde{\chi}^+_1 \tilde{\chi}^-_1 & \to & \ell^+\nu\nu \;\; \ell^-\nu\nu, \; \ell^+\ell^-\ell^+ \;\; \ell^-\nu\nu \; (+C.C), \; \ell^+\ell^-\ell^+ \;\; \ell^+\ell^-\ell^- \end{array} \tag{3}$$

where f stands for any fermion, lepton or quark.

These final states are characterized by the large number of leptons produced ($\ell = e,\ \mu,\ \tau$, depending on the considered couplings), which will be the main criterion for this search. This is a clear topology, with low level of background coming mainly from 4 fermions production.

The results of this search are displayed on the table 1.

Table 1: Results of the searches with λ couplings in 189 GeV data.

Signal	DATA	S.M. Exp.	Eff. range(%)	Excluded σ (pb)
$\tilde{\chi}^0_1 \tilde{\chi}^0_1$ Direct	3	2.0 ± 0.2	4–51	0.85–0.07
$\tilde{\chi}^+_1 \tilde{\chi}^-_1$ Direct	21	20 ± 1	9–46	0.80–0.15
$\tilde{\chi}^0_1 \tilde{\chi}^0_j$ Indirect	5	5.8 ± 0.4	47–60	0.07–0.06
$\tilde{\chi}^+_1 \tilde{\chi}^-_1$ Indirect	2	3.8 ± 0.3	14–59	0.17–0.04

These results are coming from the analysis of data collected in 1998, at $\sqrt{s}$ =189 GeV, with a total integrated luminosity of 176.8 pb^{-1}.

Good agreement is found between data and Standard Model expectations, leading to exclusion cross–section lower than 0.85 pb. Indirect and direct decays refer to decays with and without intermediate $\tilde{\chi}_1^0$ resonance.

2.2 λ' couplings

The following modes were considered:

$$\begin{aligned}
\tilde{\chi}_1^0\,\tilde{\chi}_1^0 &\rightarrow \ell q\bar{q}' \;\; \ell q\bar{q}',\; \ell q\bar{q}' \;\; \nu q\bar{q},\; \nu q\bar{q} \;\; \nu q\bar{q} \\
\tilde{\chi}_j^0\tilde{\chi}_1^0 &\rightarrow Z^*\tilde{\chi}_1^0\,\tilde{\chi}_1^0 \rightarrow f\bar{f} \;\; \ell q\bar{q}'\,\ell q\bar{q}',\; f\bar{f} \;\; \ell q\bar{q}'\,\nu q\bar{q},\; f\bar{f} \;\; \nu q\bar{q}\,\nu q\bar{q} \\
\tilde{\chi}_1^+\,\tilde{\chi}_1^- &\rightarrow W^*\tilde{\chi}_1^0\,W^*\tilde{\chi}_1^0 \rightarrow many\ channels. \\
\tilde{\chi}_1^+\,\tilde{\chi}_1^- &\rightarrow \ell q\bar{q}' \;\; \ell q\bar{q}',\; \ell q\bar{q}' \;\; \nu q\bar{q},\; \nu q\bar{q} \;\; \nu q\bar{q}
\end{aligned} \tag{4}$$

These final states contain both leptons and jets, both used in this kind of search. The several chargino final states have been gathered on four main topologies, jets alone, jets + leptons, jets + missing momentum, jets + leptons + missing momentum.

Leptons are useful to reduce the large background from 4 fermion production, namely semileptonic decays of W and Z pairs, as one can notice comparing the tables 1 and 2.

Table 2: Results of the searches with λ' couplings in 189 GeV data.

Signal	DATA	S.M.Exp.	Eff.(%)	Excl. σ (pb)
$\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	41	44 ± 1	11–23	0.65–0.31
$\tilde{\chi}_1^+\,\tilde{\chi}_1^-$,$\tilde{\chi}_i^0\tilde{\chi}_j^0$	257	262 ± 12	31–70	0.55–0.24

The large level of background in the second line comes mainly from the topology with jets only. This topology is also found in the λ'' analyses. Excluded cross–sections are now below 0.65 pb.

2.3 λ'' couplings

The following final states were studied:

$$\begin{aligned}
\tilde{\chi}_1^0\,\tilde{\chi}_1^0 &\rightarrow qqq \;\; qqq \\
\tilde{\chi}_j^0\tilde{\chi}_1^0 &\rightarrow Z^*\tilde{\chi}_1^0\,\tilde{\chi}_1^0 \rightarrow f\bar{f} \;\; qqq\; qqq \\
\tilde{\chi}_1^+\,\tilde{\chi}_1^- &\rightarrow W^*\tilde{\chi}_1^0\,W^*\tilde{\chi}_1^0 \rightarrow f\bar{f}'\; qqq \;\; f\bar{f}'\; qqq \\
\tilde{\ell}_R^+\tilde{\ell}_R^- &\rightarrow \ell^+\tilde{\chi}_1^0\,\ell^-\tilde{\chi}_1^0 \rightarrow \ell^+\; qqq \;\; \ell^-\; qqq
\end{aligned} \tag{5}$$

These final states are characterized by their large number of jets, that will be mainly used to reduce the large hadronic background coming from 4 jets production.

Results from the different selections performed are gathered in table 3.

Table 3: Results of the searches with λ'' couplings in 202 GeV data.

Signal	DATA	S.M. Exp.	Eff. (%)	Excl. σ (pb)
$\tilde{\chi}_1^0\,\tilde{\chi}_1^0$	50	56 ± 1	29–54	1.17–0.63
$\tilde{\chi}_1^+\,\tilde{\chi}_1^-\,,\tilde{\chi}_i^0\tilde{\chi}_j^0$	23	25.4 ± 0.8	38–72	0.71–0.37
$\tilde{e}_R^+\tilde{e}_R^-,\tilde{\mu}_R^+\tilde{\mu}_R^-$	3	2.6 ± 0.9	29–69	0.52–0.22
$\tilde{\tau}_R^+\tilde{\tau}_R^-$	30	34.0 ± 0.8	39–66	0.70–0.41

Scalar leptons were also studied within this framework. These results are coming from the study of the data collected in 1999 at $\sqrt{s} = 202$ GeV, with a luminosity of 37 pb^{-1}.

Due to reduced luminosity with respect to 189 GeV data, excluded cross–sections are going up to 1.17 pb.

3 Limits

The absence of significant excess have allowed to derive upper limits on the production of supersymmetric particles in the pb range.

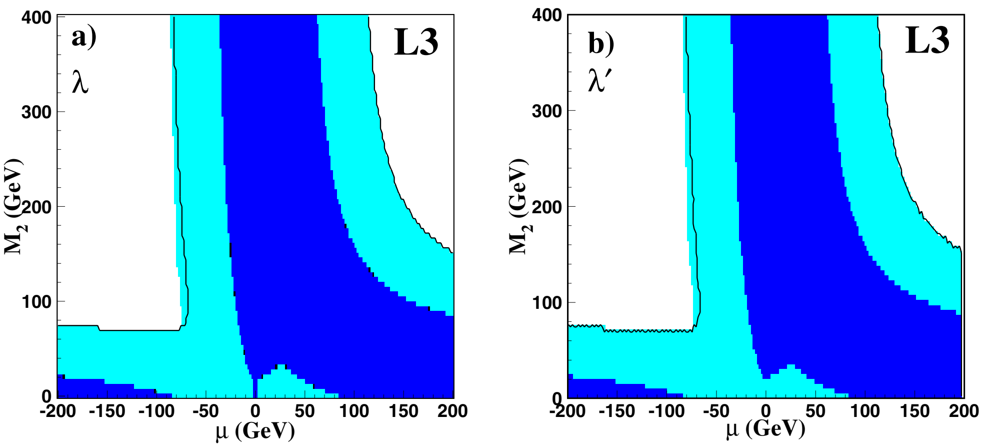
One can translate these limits into limits on supersymmetric particles masses in the framework of the constrained MSSM, where all the relevant physical parameters (production cross–sections, branching ratios, mixings and field contents of the supersymmetric particles) depend only on four parameters:

- M_2 = Mass term for SU(2) gauginos.
- m_0 = common scalar mass at GUT scale
- μ = mixing parameter between the two Higgs doublets.
- $\tan\beta$ = ratio of vacuum expectation values of the scalar Higgses.

Fixing two parameters (m_0 and $\tan\beta$), we derive exclusion contours in the $M_2 - \mu$ plane according to the obtained excluded cross–sections, one point of the MSSM parameter space being excluded if the production cross–sections of the studied processes is greater than the excluded cross–section.

All the analyses are combined since several processes can occured at a given point.

The results are displayed on the sample scans pictured on figure 1:



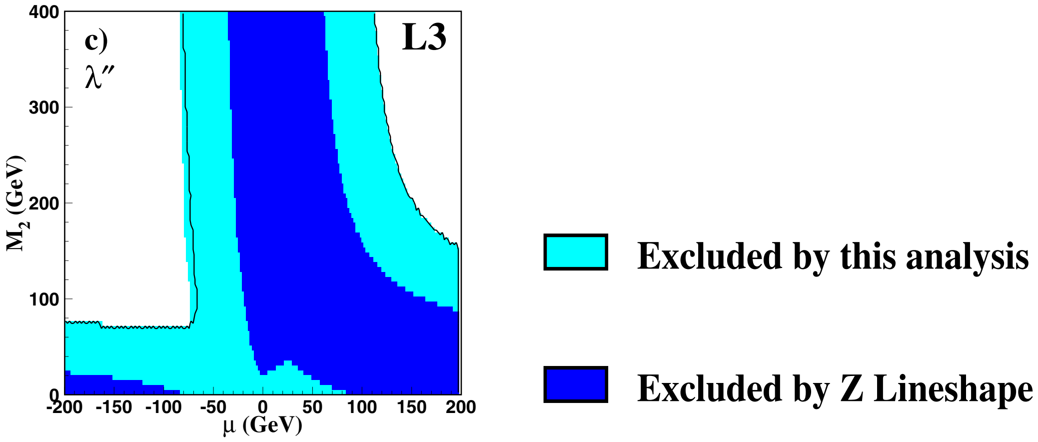


Figure 1: Exclusion contours obtained with the different kind of $\not{R}_p$ couplings studied, in the $M_2 - \mu$ plane, with $m_0 = 500$ GeV and $\tan\beta = 1.41$.

The black region is excluded by Z total width measurement performed at LEP I[6].

The grey region is excluded by these analyses and the plain line is the chargino kinematic limit. Exclusion above the kinematic limit is here due to heavy neutralino contributions $(\tilde{\chi}^0_i\tilde{\chi}^0_j; i,j \neq 1)$.

Performing a complete scan along m_0 and $\tan\beta$, one can derive limits on the studied supersymmetric particle masses, limits that are reproduced in table 4.

Table 4: Limits on supersymmetric particles masses obtained by the different analyses.

SUSY particle	λ	λ'	λ''
$\tilde{\chi}^0_1$	M>30.5 GeV	M>32.4 GeV	M>37.5 GeV
$\tilde{\chi}^0_2$	M>50.5 GeV	M>67.6 GeV	M>73.0 GeV
$\tilde{\chi}^\pm_1$	M>94.3 GeV	M>94.0 GeV	M>99.8 GeV

Limits from λ'' analyses are updates from 202 GeV data analysis. The two other sets are obtained at $\sqrt{s} = 189$ GeV, and the main difference between λ and λ' limits is due to missing heavy neutralino channels that are not yet included to derive these limits. The final values will appear in[5] and should be very close.

The other LEP experiments have also provided similar results on R–Parity violation[7], limits that are competitive and complementary to those obtained in this article.

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